

On Systematic Errors in observing Right Ascensions of Nebulæ.

By J. L. E. Dreyer, Ph.D.

Although a great number of micrometer measures of nebulæ have been made during the last forty years, it has hitherto not been found feasible to combine the results into a general catalogue of accurate positions of nebulæ, owing to the systematic errors with which the observations of Right Ascension are more or less affected. Attention was first drawn to these errors by Julius Schmidt (*Astr. Nachr.*, No. 1463), who pointed out that Schönfeld's Right Ascensions, deduced from observations made with an annular micrometer, were systematically smaller than those found by himself with a similar micrometer, and, as was soon afterwards found, smaller than those of several other observers. In 1875, when the extensive and valuable series of filar-micrometer observations by Schultz had been published, I compared them with Schönfeld's, using only those objects which the two observers had compared with the same star, and I found from 113 objects the very pronounced difference Schönfeld I. — Schultz = $-0^s.34$. It appeared, furthermore, as already noticed by Schmidt, that the difference depended to a great extent on the degree of condensation of the objects. Dividing these into three classes according as they had a sharp nucleus, were fairly condensed or wanting any condensation, the difference was found to be *

I.	$\Delta\alpha \cos \delta = -0^s.15$	from 32 neb.
II.	$-0^s.39$	„ 53 „
III.	$-0^s.44$	„ 28 „

Shortly afterwards Schönfeld published his second series of measures, and, as might have been expected, the knowledge that he observed transits of nebulous objects too early led to a reduction of his personal error, the difference Schönfeld II. — Schultz being $= -0^s.15$. From this and the former difference there results Sch. I. — II. = $-0^s.19$, while the direct comparison between the two series gave $-0^s.21$, and an indirect comparison by means of Rümker's measures gave $-0^s.25$.†

Every series of observations which has been published since has confirmed the reality of these errors in the observed Right Ascensions, while differences in declination between various observers appear to be mere accumulations of accidental errors. Thus M. d'Engelhardt gives the following differences between

* *Vierteljahrsschrift d. Astr. Ges.*, vol. x. p. 72.† *Ibid.*, vol. xi. p. 274.

his own measures and those of a number of other observers, which are in good accordance with the differences quoted above.*

Sch. I.	—Eng.	^s = -0·55	57 objects
Sch. II.	„	-0·39	60 „
Schultz	„	-0·21	70 „
Vogel	„	-0·18	50 „
Rümker	„	-0·27	31 „
Engelmann	„	-0·04	46 „
Auwers	„	-0·18	12 „
Oppolzer	„	-0·15	7 „
Ginzel	„	0·00	14 „
Dreyer	„	-0·47	22 „
Porter	„	-0·42	16 „
Weinek	„	+0·22	14 „
Gruss	„	-0·28	14 „
Kempf	„	-0·26	33 „

The mean of these fourteen equations is $-0^s.23$, which tends to show that Schultz's measures are probably nearly free from these systematic errors. It will also be seen that my own error lies between those of Schönfeld's two series, as I have also found by direct comparison.†

Schönfeld	I. — Dreyer	^s = -0·11	27 neb.
„	II. „	= +0·04	38 „

In the summer of 1895 it occurred to me that it might be possible for an observer with a filar micrometer to determine his own personal error in a very simple manner. As there is every reason to believe that measures of difference of declination between a nebula and a star are practically free from systematic error (or at all events from any errors approaching in magnitude to those of the transit observations), a difference of Right Ascension between a nebula and an adjacent star might be measured both by transits and by the micrometer screw. Assuming, then, that the screw measures represented the true $\Delta\alpha$, the difference between them and the transits would directly give the error of the latter. In order to be perfectly free from bias I postponed the carrying out of this idea for some months, and abstained in the meanwhile from reading anything about measures of nebulæ. The reduction of the observations, and even the copying of them

* *Observations Astronomiques*, t. iii. p. 28.

† *Trans. Royal Irish Acad.*, vol. xxx. p. 522.

from the rough note-book into the volume of refractor observations, was also deferred until the final close of the series of measures; and, as I had even forgotten the signs of the differences between other observers and myself, I feel perfectly convinced that the results of these measures are altogether free from any conscious bias.

The observations given in the following table were made with the 10-inch refractor and the same filar micrometer with which my previous measures were taken. T is the $\Delta\alpha$ (nebula minus star) observed by transits with eye and ear, from ten to sixteen single-wire transits being generally taken; M is the same $\Delta\alpha$ measured four or five times with the screws while the clock was carrying the telescope along. In the column "Cond." the nebulae are classified according to whether they have a fairly sharp nucleus (1), or are more or less devoid of condensation (2). The column "Star" gives the magnitude of the comparison star and its place relative to the nebula. The $\Delta\delta$ was generally small. I give the results in full, as they may eventually be of use in determining proper motions of the objects.

G.C.	Date.	T.	M.	M-T.	Cond.	Star.	Notes.
		^s	^s	^s			
307	4 1 96	+20.12	+20.13	+0.01	1	10.5, n p	Good object.
1904	1 4 96	+12.99	+13.42	+0.43	2	12, s p	
2038	1 4 96	-34.93	-35.43	+0.50	1	11, f	
2041	1 4 96	-6.02	-5.88	+0.14	1	11, n f f	
2102	1 4 96	-19.82	-19.48	+0.34	2	10, s f	
3227	8 5 96	-39.09	-39.55	-0.46	1	10, s f f	
	12 5 96	-38.95	-39.05	-0.10	1		Not B, twilight and haze.
3615	8 5 96	+37.57	+37.69	+0.12	1	11, p	
	12 5 96	+37.67	+37.71	+0.04	1		
4473	5 9 96	+44.53	+44.76	+0.23	2	9.5, p	Very soft condens.
4499	1 9 96	-15.95	-16.06	-0.11	2	9, s f	Almost like a cluster.
	5 9 96	-16.07	-15.97	+0.10	2		Nice object.
4510	10 9 96	+14.98	+15.08	+0.10	2	11.5, p	
	11 9 96	+15.01	+15.18	+0.17	2	12, p	
4572	19 9 95	+53.97	+54.51	+0.54	2	9.0 p	
	21 9 95	+54.15	+54.69	+0.54	2		
4586	22 9 95	+7.34	+7.41	+0.07	2	9, s p p	
	16 10 95	+7.36	+7.32	-0.04	2		
4608	22 9 95	-18.62	-18.55	+0.07	2	9.5, f	
	17 10 95	-19.34	-18.70	+0.64	2		L, v l b M, l E p f (* is s p one of 2).
4625	20 9 95	+46.53	+46.73	+0.20	1	8.5, s p	
	21 9 95	+46.72	+47.04	+0.32	1		

G.C.	Date.	T.	M.	M-T.	Cond.	Star.	Notes.
4678	19 9 95	-11 ^s 65	-11 ^s 08	+0 ^s 57	2	9.5, n f	
	21 9 95	-11 48	-10 79	+0 69	2		Good object to measure.
4734	20 9 95	+12 10	+12 29	+0 19	1	10, n n p	
	22 9 95	+11 68	+12 22	+0 54	1	9.5, n n p	
4760	1 9 96	-13 37	-12 91	+0 46	2	11, s f	B, p L.
	5 9 96	-13 42	-13 07	+0 35	2		
4808	22 10 95	- 6 13	- 6 10	+0 03	1	10, n f	p F, p L, m b M.
4815	10 9 96	-33 78	-34 14	-0 36	1	11, n f	
	11 9 96	-34 01	-34 13	-0 12	1		
4821	16 10 95	- 3 37	- 2 97	+0 40	1	10, s s f	s m b M.
	17 10 95	- 3 31	- 3 22	+0 09	1		
4824	17 10 95	+18 32	+18 57	+0 25	2	Same *	
4879	17 10 95	-10 37	-10 20	+0 08	2	10, f	
	18 10 95	-10 34	-10 39	-0 05	2		
4880	17 10 95	-19 36	-18 81	+0 45	2	9, f	Rather F for B wires.
	18 10 95	-19 76	-18 74	+1 02	2		v l condens., diffused.
4921	22 10 95	+25 44	+25 81	+0 37	1	8.5, n p	p B, p L, m b M.
	14 11 95	+25 15	+25 77	+0 62	1		p F.
4939	1 11 96	-26 70	-26 75	-0 05	2	8, n f f	Brighter towards a point nearer s f edge.
	3 11 96	-26 67	-26 46	+0 19	2	7.5, f	
4966	22 10 95	+ 8 63	+ 8 75	+0 12	1	9.5, p	
	11 12 95	+ 8 63	+ 8 44	-0 19	1		
5020	1 11 96	+39 70	+40 16	+0 46	2	10, s p	[n p]
	4 11 96	+39 62	+39 50	-0 12	2	11, n p	* almost in line with 2 neb.
5022	4 11 96	+60 23	+60 32	+0 09	2	Same *	
5029	5 11 96	+17 40	+17 41	+0 01	1	8.8, p	

The mean of the column M-T ought now to represent my personal error, and is

$$+0^s.206$$

or $+0^s.202$ of each value of M-T is multiplied by $\cos \delta$.

Taking the two classes of objects separately we get:

For much condensed nebulae	+0 ^s 118
For little condensed nebulae	+0 277

The result of this investigation is, therefore, that I am, like Schönfeld, inclined to note the transits of nebulous objects too early, and that my error, like his, is much smaller for a nebula

with a good nucleus than for more diffused objects—which is only natural. Though I am not conscious of any peculiarity in my mode of observing, I am inclined to think that this error may arise from the fact that the nebula on approaching the illuminated wire becomes somewhat fainter, which may induce an observer to anticipate the actual moment of transit.

It is of interest to compare my results with those of a recent attempt by Dr. Mönnichmeyer, of Bonn, to deduce the corrections necessary to reduce various observations of nebulae to a homogeneous system.* Dr. Mönnichmeyer, who has observed about two hundred nebulae with an annular micrometer, first determined his own personal error in star transits, as far as it depends on magnitude, by observing stars of various magnitudes in the *Pleiades*, and comparing the results with Dr. Elkin's heliometer measures. This equation depending on magnitude he calls ΔH_a^* . Supposing now that his nebular personal error is approximately represented by his stellar error thus found, then, if Schultz's and Vogel's results are practically free from systematic errors, the differences between their Right Ascensions and those of Dr. Mönnichmeyer ought to be equal to this ΔH_a . And even if the measures of Schultz and Vogel are affected by sensible errors, the said differences might still be represented by ΔH_a , if M's personal equation is a product of various sources of error, by some of which the observations of Schultz and Vogel are equally affected. In this case the ΔH_a would represent the reductions of M's observations to the "filar micrometric system of Schultz and Vogel"; and if all measures can be reduced to a common system, it will of course be of no consequence for future investigations of proper motion whether ΔH_a is to be considered as relative or absolute error. Assigning a certain stellar magnitude to every observed nebula, Dr. Mönnichmeyer divides the objects into classes according to the difference of magnitude between nebula and comparison star. From the difference "other observer minus Mönnichmeyer" ΔH_a is subtracted, and the difference is called $\Delta \alpha'$. This should be zero, if ΔH_a represents the reduction to a common system, and so it is in the cases of Schultz and Vogel. If not equal to zero, $\Delta \alpha'$ represents the personal error of the other observer. In this manner the following constant personal errors were found:—

Schönfeld I.	^s +0.24	Engelhardt	^s -0.21
Schönfeld II.	+0.09	Kempf	+0.05
Dreyer	+0.14		

These observers seem, therefore, not to be sensibly influenced by the difference of magnitude between nebula and star. But Schmidt's Right Ascensions appear to be affected by approximately the same systematic errors as those of Dr. Mönnichmeyer

* *Veröffentlichungen der K. Sternwarte zu Bonn*, No. 1, "Beobachtungen von Nebelflecken am sechszölligen Refractor von Dr. C. Mönnichmeyer."

are, as Schmidt's error is $=\frac{4}{3} \Delta H_a$. Similarly Rümker's error is $=\frac{5}{4} \Delta H_a$, and Ginzel's $=2 \Delta H_a$. As a final test of all these results, they were applied to the single differences between M and the various observers, and the mean Δa comes out as $0^s.00$ or $0^s.01$ in all cases except that of Ginzel, where it is $+0^s.04$, so that his personal error as found by this investigation is a little too small, while the reduction to the Vogel-Schultz system in the other cases seems a perfect one. Though these results, considered as absolute personal errors, perhaps in some cases (*e.g.* in Schönfeld's, where they seem rather smaller than we should have expected) may be a little modified by future investigations, the differences between them agree well with those found by direct comparison.

My own relation to Schultz may be made out in several ways, either by direct comparison or through the medium of other observers. I have already in the paper in the *Trans. R.I. Acad.* given the result of the direct comparison of twenty-six objects observed by Schultz and myself, viz. Schultz—Dreyer $= +0^s.07$; but this is not entitled to any great weight, as twelve of the objects are well condensed and give $0^s.00$, while only fourteen are slightly condensed and give $+0^s.13$. The results of indirect comparison through four observers, with whom both Schultz and I have many objects in common, are probably much more reliable, and they agree closely *inter se*.

Through Schönfeld I.	^s $+0^s.23$
„ „ II.	$+0^s.19$
„ Engelhardt	$+0^s.25$
„ Mönnichmeyer	$+0^s.18$
Mean	$+0^s.21$

As this result for the difference Schultz-Dreyer is in perfect accordance with my absolute personal error as found from my recent observations, it may be assumed as well-established facts that Schultz's observations are practically free from systematic errors, and that my own absolute error in observing transits of nebulae is very close to $+0^s.2$. It is true that the value found by Dr. Mönnichmeyer for the latter quantity, $+0^s.14$, is somewhat smaller; but as it was only derived from nineteen objects, nearly all (by ill luck) having a strong central condensation, this smaller value is also in very good agreement with the absolute error ($+0^s.12$) which I found for nebulae with a well-marked nucleus.

We may therefore look forward to the ultimate determination of proper motions of nebulae with more confidence than hitherto, as we are getting the systematic errors well under control. The fact must, however, not be lost sight of, that in applying corrections for personal error to the observed places

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proper attention must be paid to the degree of condensation of the objects. But there is an obvious way of avoiding systematic errors altogether (except such as are well within the limit of accuracy attainable in such observations) by giving up observations of transits and measuring both $\Delta\alpha$ and $\Delta\delta$ by the micrometer screw. As this can only be done by selecting comparison stars among those visible in the same field with each nebula, and such stars in many cases cannot be observed on the meridian, observers will have to sacrifice the pleasure of putting together a list of Right Ascensions and Declinations of the nebulae they have measured. But this small sacrifice will be well compensated by the avoidance of the difficulty of assigning to each object the proper amount of systematic error.

Armagh Observatory:
1896 December.

On the Inequality in the Apparent Diurnal Movement of Stars due to refraction, and a method of allowing for it in Astronomical Photography. By Prof. Arthur A. Rambaut, M.A., D.Sc.

It is obvious that the varying effect of refraction in the Earth's atmosphere to which the light of a star is subjected as its hour-angle changes will cause inequalities in its apparent diurnal movement, and that no uniform equatorial movement will enable a telescope to follow a star for long periods of time when the highest accuracy is aimed at.

The irregularities in the apparent motion of stars due to local and temporary changes in the refraction are well known to astronomers who have had experience in stellar photography, but I doubt whether the perfectly regular and systematic change as the star alters its position in the sky has received the attention on the part of astronomers which its importance seems to demand.

Speaking generally, the hour-angle of a star is diminished by the refraction when approaching its upper culmination, but to a continually decreasing extent, and consequently the motion of the star at this part of its course appears slower than it actually is. At first sight it might perhaps appear that the effect at the western side of the meridian would be of an exactly opposite kind, and that the stars at this part of their diurnal track would appear to move more rapidly than they actually do. But a moment's reflection will show that this is not the case, for the refraction throwing the apparent to the following side of the true image in this case, and the displacement continually increasing as the star sinks in the west, the apparent will fall ever more and more behind the true position.